[0001]   PROCESSING FOR IMPROVED PERFORMANCE AND REDUCED PILOT

[0002]   Cross Reference to Related Applications

[0003]   This application a continuation of Application No. 10/357,869, filed on February 3, 2003, which is a continuation of Application No. 10/043,850, filed on January 11, 2002, now issued Patent No. 6,516,022, issued on February 4, 2003, which is a continuation of Application No. 09/078,417, filed on May 14, 1998, now issued Patent No. 6,366,607, issued on April 2, 2002.

[0004]   BACKGROUND

[0005]   Field of the Invention

[0006]   The present invention relates generally to digital communications. More specifically, the invention relates to a system for and method of using a code division multiple access air interface which greatly reduces the signal power required for the global and assigned-pilots while improving performance by using the quadrature phase shift keyed (QPSK) traffic signal for a particular channel to perform channel estimation and carrier recovery.

[0007]   Description of the Prior Art

[0008]   Most advanced communication technology today makes use of digital spread spectrum modulation or code divisional multiple access (CDMA). Digital spread spectrum is a communication technique in which data is transmitted with a broadened band (spread spectrum) by modulating the data to be transmitted with a pseudo-noise signal. CDMA can transmit data without being affected by signal distortion or an interfering frequency in the transmission path.

[0009] Shown in Figure 1 is a simplified CDMA communication system that involves a single communication channel of a given bandwidth which is mixed by a spreading code which repeats a predetermined pattern generated by a pseudo-noise (pn) sequence generator. A data signal is modulated with the pn sequence producing a digital spread spectrum signal. A carrier signal is then modulated with the digital spread spectrum signal establishing a forward link, and transmitted. A receiver demodulates the transmission extracting the digital spread spectrum signal. The transmitted data is reproduced after correlation with the matching pn sequence. The same process is repeated to establish a reverse link.

[0010] During terrestrial communication, a transmitted signal is disturbed by reflection due to varying terrain and environmental conditions and man-made obstructions. This produces a plurality of received signals with differing time delays at the receiver. This effect is commonly known as multipath propagation. Moreover, each path arrives delayed at the receiver with a unique amplitude and carrier phase.

[0011] To identify the multiple components in the multipath propagation, the relative delays and amplitudes and phases must be determined. This determination can be performed with a modulated data signal, but typically, a more precise rendering is obtained when compared to an unmodulated signal. In most digital spread spectrum systems, it is more effective to use an unmodulated pilot signal discrete from the transmitted modulated data by assigning the pilot an individual pn sequence. A global-pilot signal is most valuable on systems where many signals are transmitted from a base station to multiple users.

[0012] In the case of a base station which is transmitting many channels, the global-pilot signal provides the same pilot sequence to the plurality of users serviced by that particular base station and is used for the initial acquisition of an individual user and for the user to obtain channel-estimates for coherent reception and for the

combining of the multipath components. However, at the required signal strength, the global-pilot signal may use up to 10 percent of the forward direction air capacity.

[0013]   Similar multipath distortion affects a user's reverse link transmission to the base station. Inserting in each individual user's return signal an assigned-pilot may consume up to 20 percent of the total reverse channels air capacity.

[0014]   Without phase and amplitude estimation, noncoherent or differentially coherent reception techniques must be performed. Accordingly, there exists a need for a coherent demodulation system that reduces the air capacity of the global-pilot and assigned-pilot signals while maintaining the desired air-interface performance.

[0015]   SUMMARY

[0016]   The present invention is a user equipment (UE), including a receiver and method for receiving one of a plurality of channels in a communication signal. An adaptive matched filter produces a filtered signal by using a weighting signal. A rake receiver produces a filter weighting signal using a pseudo-noise signal generator. A channel despreader despreads the filtered signal using the pseudo-noise signal generated to produce a despread channel signal of the selected channel. A pilot channel despreader despreads the filtered signal using a pseudo-noise signal generator to produce a despread pilot signal of the pilot channel. A hard decision processor receives the despread channel signal of the selected channel and produces a correction signal. A phase-locked loop utilizes at least the despread pilot signal and produces a phase correction signal which is applied to produce phase-corrected channel signals.

[0017]   Accordingly, it is an object of the present invention to provide a code division multiple access communication system which reduces the required global and assigned-pilot signal strength.

[0018]   It is a further object of the invention to reduce the transmitted levels of the global and assigned-pilots such that they consume negligible overhead in the air interface while providing information necessary for coherent demodulation.

[0019]   Other objects and advantages of the system and method will become apparent to those skilled in the art after reading the detailed description of the preferred embodiment.

[0020]   BRIEF DESCRIPTION OF THE DRAWINGS

[0021]   Figure 1 is a simplified block diagram of a typical, prior art, CDMA communication system.

[0022]   Figure 2 is a detailed block diagram of a B-CDMAJ communication system.

[0023]   Figure 3A is a plot of an in-phase bit stream.

[0024]   Figure 3B is a plot of a quadrature bit stream.

[0025]   Figure 3C is a plot of a pseudo-noise (pn) bit sequence.

[0026]   Figure 4 is a detailed block diagram of the present invention using one pseudo-pilot signal, with carrier-offset correction implemented at the chip level.

[0027]   Figure 5 is a block diagram of a rake receiver.

[0028]   Figure 6 is a diagram of a received symbol p_o on the QPSK constellation showing a hard decision.

[0029]   Figure 7 is a diagram of the angle of correction corresponding to the assigned symbol.

[0030]   Figure 8 is a diagram of the resultant symbol error after applying the correction corresponding to the assigned symbol.

[0031]   Figure 9 is a block diagram of a conventional phase-locked loop.

[0032]   Figure 10 is a detailed block diagram of the present invention using a pseudo-pilot signal with carrier-offset correction implemented at the symbol level.

[0033]   Figure 11 is a detailed block diagram of the present invention using a pseudo-pilot signal and the MIPLL, with carrier-offset correction implemented at the chip level.

[0034]   Figure 12 is a block diagram of the multiple input phase-locked loop (MIPLL).

[0035]   Figure 13 is a detailed block diagram of the present invention using a pseudo-pilot signal and the MIPLL, with carrier-offset correction implemented at the symbol level.

[0036]   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0037]   The preferred embodiment will be described with reference to the drawing figures where like numerals represent like elements throughout.

[0038]   A B-CDMAJ communication system 25 as shown in Figure 2 includes a transmitter 27 and a receiver 29, which may reside in either a base station or a mobile user receiver. The transmitter 27 includes a signal processor 31 which encodes voice and nonvoice signals 33 into data at various rates, e.g. data rates of 8 kbps, 16 kbps, 32 kbps, or 64 kbps. The signal processor 31 selects a rate in dependence upon the type of signal, or in response to a set data rate.

[0039]   By way of background, two steps are involved in the generation of a transmitted signal in a multiple access environment. First, the input data 33 which can be considered a bi-phase modulated signal is encoded using forward error-correcting coding (FEC) 35. For example, if a R=2 convolution code is used, the single bi-phase modulated data signal becomes bivariate or two bi-phase modulated signals. One signal is designated the in-phase channel I 41a. The other signal is designated the quadrature channel Q 41b. A complex number is in the form $a+bj$, where a and b are real numbers and $j^2=-1$. Bi-phase modulated I and Q signals are usually referred to as quadrature phase shift keying (QPSK). In the preferred embodiment, the tap

generator polynomials for a constraint length of K=7 and a convolutional code rate of R=2 are $G_1=171_8$ 37 and $G_2=133_8$ 39.

[0040]   In the second step, the two bi-phase modulated data or symbols 41a, 41b are spread with a complex pseudo-noise (pn) sequence. The resulting I 45a and Q 45b spread signals are combined 53 with other spread signals (channels) having different spreading codes, multiplied (mixed) with a carrier signal 51, and transmitted 55. The transmission 55 may contain a plurality of individual channels having different data rates.

[0041]   The receiver 29 includes a demodulator 57a, 57b which mixes down the transmitted broadband signal 55 into an intermediate carrier frequency 59a, 59b. A second down conversion reduces the signal to baseband. The QPSK signal is then filtered 61 and mixed 63a, 63b with the locally generated complex pn sequence 43a, 43b which matches the conjugate of the transmitted complex code. Only the original waveforms which were spread by the same code at the transmitter 27 will be effectively despread. Others will appear as noise to the receiver 29. The data 65a, 65b is then passed onto a signal processor 59 where FEC decoding is performed on the convolutionally encoded data.

[0042]   As shown in Figures 3A and 3B, a QPSK symbol consists of one bit each from both the in-phase (I) and quadrature (Q) signals. The bits may represent a quantized version of an analog sample or digital data. It can be seen that symbol duration t_s is equal to bit duration.

[0043]   The transmitted symbols are spread by multiplying the QPSK symbol stream by a unique complex pn sequence. Both the I and Q pn sequences are comprised of a bit stream generated at a much higher rate, typically 100 to 200 times the symbol rate. One such pn sequence is shown in Figure 3C. The complex pn sequence is mixed with the complex-symbol bit stream producing the digital spread

signal. The components of the spread signal are known as chips having a much smaller duration t_c.

[0044]   When the signal is received and demodulated, the baseband signal is at the chip level. Both the I and Q components of the signal are despread using the conjugate of the pn sequence used during spreading, returning the signal to the symbol level. However, due to carrier-offset, phase corruption experienced during transmission manifests itself by distorting the individual chip waveforms. If carrier-offset correction is performed at the chip level, it can be seen that overall accuracy increases due to the inherent resolution of the chip-level signal. Carrier-offset correction may also be performed at the symbol level, but with less overall accuracy. However, since the symbol rate is much less than the chip rate, less overall processing speed is required when the correction is done at the symbol level.

[0045]   System architectures for receivers taught in accordance with the system and method of the present invention that do not require large magnitude pilot signals follow. The following systems replace the filtering, despreading and signal processing shown in Figure 2. The systems are implemented with carrier-offset correction at both the chip and symbol levels.

[0046]   As shown in Figure 4, a receiver using the system 75 and method of the present invention is shown. A complex baseband digital spread spectrum signal 77 comprised of in-phase and quadrature phase components is input and filtered using an adaptive matched filter (AMF) 79 or other adaptive filtering means. The AMF 79 is a transversal filter (finite impulse response) which uses filter coefficients 81 to overlay delayed replicas of the received signal 77 onto each other to provide a filtered signal 83 having an increased signal-to-noise ratio (SNR). The output 83 of the AMF 79 is coupled to a plurality of channel despreaders 85_1, 85_2, 85_n and a pilot despreader 87. In the preferred embodiment, n=3. The pilot signal 89 is despread with a separate despreader 87 and pn sequence 91 contemporaneous with the transmitted data 77

assigned to channels which are despread 85_1, 85_2, 85_n with pn sequences 93_1, 93_2, 93_n of their own. After the data channels are despread 85_1, 85_2, 85_n, the data bit streams 95_1, 95_2, 95_n are coupled to Viterbi decoders 97_1, 97_2, 97_n and output 99_1, 99_2, 99_n.

[0047]   The filter coefficients 81, or weights, used in adjusting the AMF 79 are obtained by the demodulation of the individual multipath propagation paths. This operation is performed by a rake receiver 101. The use of a rake receiver 101 to compensate for multipath distortion is well known to those skilled in the communication arts.

[0048]   As shown in Figure 5, the rake receiver 101 consists of a parallel combination of path demodulators (Afingers@) 103_0, 103_1, 103_2, 103_n which demodulate a particular multipath component. The pilot sequence tracking loop of a particular demodulator is initiated by the timing estimation of a given path as determined by a pn sequence 105. In the prior art, a pilot signal is used for despreading the individual signals of the rake. In this embodiment of the present invention, the pn sequence 105 may belong to any channel 93_1 of the communication system. The channel with the largest received signal is typically used.

[0049]   Each path demodulator includes a complex mixer 107_0, 107_1, 107_2, 107_n, and summer and latch 109_0, 109_1, 109_2, 109_n. For each rake element, the pn sequence 105 is delayed τ 111_1, 111_2, 111_n by one chip and mixed 107_1, 107_2, 107_n with the baseband spread spectrum signal 113 thereby despreading each signal. Each multiplication product is input into an accumulator 109_0, 109_1, 109_2, 109_n where it is added to the previous product and latched out after the next symbol-clock cycle. The rake receiver 101 provides relative path values for each multipath component. The plurality of n-dimension outputs 115_0, 115_1, 115_2, 115_n provide estimates of the sampled channel impulse response that contain a relative phase error of either $0\square$, $90\square$, $180\square$, or $270\square$.

[0050]   Referring back to Figure 4, the plurality of outputs from the rake receiver are coupled to an n-dimensional complex mixer 117. Mixed with each rake receiver 101 output 115 is a correction to remove the relative phase error contained in the rake output.

[0051]   A pilot signal is also a complex QPSK signal, but with the quadrature component set at zero. The error correction 119 signal of the present invention is derived from the despread channel 95_1 by first performing a hard decision 121 on each of the symbols of the despread signal 95_1. A hard decision processor 121 determines the QPSK constellation position that is closest to the despread symbol value.

[0052]   As shown in Figure 6, the Euclidean distance processor compares a received symbol p_0 of channel 1 to the four QPSK constellation points $x_{1,1}$, $x_{-1,1}$, $x_{-1,-1}$, $x_{1,-1}$. It is necessary to examine each received symbol p_0 due to corruption during transmission 55 by noise and distortion, whether multipath or radio frequency. The hard decision processor 121 computes the four distances d_1, d_2, d_3, d_4 to each quadrant from the received symbol p_0 and chooses the shortest distance d_2 and assigns that symbol location $x_{-1,1}$. The original symbol coordinates p_0 are discarded.

[0053]   Referring back to Figure 4, after undergoing each hard symbol decision 121, the complex conjugates 123 for each symbol output 125 are determined. A complex conjugate is one of a pair of complex numbers with identical real parts and with imaginary parts differing only in sign.

[0054]   As shown in Figure 7, a symbol is demodulated or derotated by first determining the complex conjugate of the assigned symbol coordinates $x_{-1,-1}$, forming the correction signal 119 which is used to remove the relative phase error contained in the rake output. Thus, the rake output is effectively derotated by the angle associated with the hard decision, removing the relative phase error. This operation effectively provides a rake that is driven by a pilot signal, but without an absolute phase reference.

[0055] Referring back to Figure 4, the output 119 from the complex conjugate 123 is coupled to a complex n-dimensional mixer 117 where each output of the rake receiver 101 is mixed with the correction signal 119. The resulting products 127 are noisy estimates of the channel impulse response p_1 as shown in Figure 8. The error shown in Figure 8 is indicated by a radian distance of $\pi/6$ from the in-phase axis.

[0056] Referring back to Figure 4, the outputs 129 of the complex n-dimensional mixer 117 are coupled to an n-dimensional channel estimator 131. The channel estimator 131 is a plurality of low-pass filters filtering each multipath component. The outputs of the n-dimensional mixer 117 are coupled to the AMF 79. These signals act as the AMF 79 filter weights. The AMF 79 filters the baseband signal to compensate for channel distortion due to multipath without requiring a large magnitude pilot signal.

[0057] Rake receivers 101 are used in conjunction with phase-locked loop (PLL) 133 circuits to remove carrier-offset. Carrier-offset occurs as a result of transmitter/receiver component mismatches and other RF distortion. The present invention 75 requires that a low level pilot signal 135 be produced by despreading 87 the pilot from the baseband signal 77 with a pilot pn sequence 91. The pilot signal is coupled to a single input PLL 133. The PLL 133 measures the phase difference between the pilot signal 135 and a reference phase of 0. The despread pilot signal 135 is the actual error signal coupled to the PLL 133.

[0058] A conventional PLL 133 is shown in Figure 9. The PLL 133 includes an arctangent analyzer 136, complex filter 137, an integrator 139 and a phase-to-complex-number converter 141. The pilot signal 135 is the error signal input to the PLL 133 and is coupled to the complex filter 137. The complex filter 137 includes two gain stages, an integrator 145 and a summer 147. The output from the complex filter is coupled to the integrator 139. The integral of frequency is phase, which is output 140 to the converter 141. The phase output 140 is coupled to a converter 141 which

converts the phase signal into a complex signal for mixing 151 with the baseband signal 77. Since the upstream operations are commutative, the output 149 of the PLL 133 is also the feedback loop into the system 75.

[0059]   By implementing the hard decision 121 and derotation 123 of the data modulation, the process provides channel estimation without the use of a large pilot signal. If an error occurs during the hard decision process and the quadrant of the received data symbol is not assigned correctly, the process suffers a phase error. The probability of phase error is reduced, however, due to the increased signal-to-noise ratio of the traffic channel. The errors that occur are filtered out during the channel-estimation and carrier-recovery processes. The traffic channel is approximately 6 dB stronger (2x) than the level of the despread pilot.

[0060]   As described earlier, the present invention can also be performed with carrier-offset correction at the symbol level. An alternative embodiment 150 implemented at the symbol level is shown in Figure 10. The difference between the chip and symbol level processes occur where the output of the conventional PLL 133 is combined. At the symbol level, the PLL output 140 does not undergo chip conversion 141 and is introduced into the AMF 79 weights after the rake receiver 101 by another n-dimensional mixer 153. The phase correction 140 feedback must also be mixed 154_1, 154_2, 154_n with the outputs 95_1, 95_2, 95_n of each of the plurality of channel despreaders 85_1, 85_2, 85_n and mixed 156 with the output 135 of the pilot despreader 87.

[0061]   As shown in Figure 11, another alternative embodiment 193 uses a variation of the earlier embodiments whereby a hard decision is rendered on each received symbol after despreading and derotated by a radian amount equal to the complex conjugate. The alternate approach 193 uses a plurality of channel despreaders 85_1, 85_2, 85_n and the pilot despreader 87 as inputs to a multiple input phase-locked loop (MIPLL) 157 shown in Figure 12. Since each of the despread channels 95_1, 95_2, 95_n contains an ambiguous representation of the pilot signal, a small

signal pilot 135 is required to serve as an absolute reference. The despread symbols from all channels in conjunction with the despread small signal pilot signal are input to the MIPLL 157.

[0062]   Referring to Figure 12, the output from each channel 95_1, 95_2, 95_n is coupled to a hard decision/complex conjugate operation 159_1, 159_2, 159_n. The derotated pseudo-pilots 161_1, 161_2, 161_n are then mixed with the delayed symbols producing a complex voltage error 163_1, 163_2, 163_n. The error 165_1, 165_2, 165_n is input into a converter 167_1, 167_2, 167_n, 167_{n+1} which takes an inverse tangent converting the complex number into a phase error 169_1, 169_2, 169_n, 169_{n+1}. Each phase error 169_1, 169_2, 169_n, 169_{n+1} is input into a maximum likelihood combiner 171 which assigns various weights to the plurality of inputs and produces a sum output. Also included in the sum is the small signal pilot 135 phase 169_{n+1} which is despread 135 and converted 167_{n+1}. The weighting of the small pilot signal may be emphasized since its phase is unambiguous.

[0063]   The output of the combiner 173 is the estimate of the carrier-offset and is coupled to a complex filter 175 and coupled to an integrator 177. All channels contribute to the estimate of the carrier-offset frequency with the absolute phase error removed by the unambiguous pilot signal. The integrator accumulates the history of the summed signal over many samples. After integration, the estimate of the phase error is output 179 converted to a complex voltage and output 183.

[0064]   Referring back to Figure 11, the output 183 of the MIPLL 157 is coupled to a complex mixer 185 upstream of the rake receiver. This completes the error feedback for the MIPLL 157. Even though this embodiment requires additional resources and complexity, the MIPLL 157 architecture can be efficiently implemented and executed in a digital signal processor (DSP).

[0065]   Referring now to the alternative embodiment 195 shown in Figure 13, this embodiment 195 mixes the output of the MIPLL 157 at the symbol level. The MIPLL

157 is mixed 197 with the output of the rake receiver 101. As described above, the output of the rake receiver 101 is at the symbol level. The symbol-to-chip conversion 181 in the MIPLL 157 architecture is disabled. Since the output 183 of the MIPLL 157 is mixed with the outputs of the rake 101 which are used only for the AMF 79 weights, the phase correction for carrier-offset must be added to the portion of the receiver that processes traffic data. A plurality of mixers 199_1, 199_2, 199_n downstream of each channel despreader 85_1, 85_2, 85_n and a mixer 193 downstream of the pilot despreader 87 are therefore required to mix the phase-corrected output 183 (at the symbol level) as feedback into the system.

[0066]   The present invention maintains the transmitted pilot signal at a low level to provide an absolute phase reference while reducing pilot interference and increasing air capacity. The net effect is the virtual elimination of the pilot overhead.

[0067]   While specific embodiments of the present invention have been shown and described, many modifications and variations could be made by one skilled in the art without departing from the spirit and scope of the invention. The above description serves to illustrate and not limit the particular form in any way.

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